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A PASSIVE MITIGATION SOLUTION TO THE EFFECTS OF HUMAN-GENERATED SOUND ON MARINE MAMMALS

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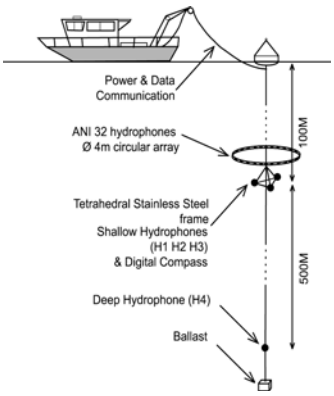
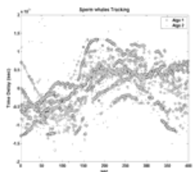


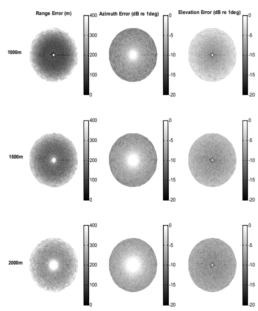
Deployment of the Technical Demonstrator



Tracked whales using the 3D localization algorithm. An automatic click detection and direction of arrival algorithm was first implemented, the results of which were compared to the same algorithm but with a much longer matching window in order to test how our simple algorithm would perform with our wider aperture array. Circled gray dots represent a perfect match between both algorithms, showing that the simulated wide aperture array is able to correctly track the detected whales.

Depth(m)	500	1000	1500	2000
Azimuth Av. Error(º)	0.32	0.42	0.54	0.68
Elevation Av. Error (º)	0.74	0.45	0.36	0.32
Range Av. Error (m)	180	123	171	279

Average error values to be expected due to cross-correlation peak time measurement error for relative animal depths of 500, 1000, 1500 and 2000m (from top array, add 100m for absolute depths) for a 2500m radius monitored area. These values are calculated removing the 5% highest errors (mostly singular results), so that they represent the expected average error produced by 95% of the data.



Estimated error maps at 1000, 1500, and 2000m depth from the top array (add 100m for absolute depths) for a 2500m radius monitored area. Except when animals are nearly aligned with the array, the angular error is less than 1º and the estimated error range from the top array is in average less than 200m (see Table)

INTRODUCTION

Acoustic and physical interactions between human activities and coincident cetacean occurrence have become a threat to marine mammal conservation. Although we do not yet fully understand under what circumstances exposure to loud sounds will cause harm to cetaceans, scientific evidence indicates that such high intensity sounds can cause lesions in acoustic organs, severe enough to be lethal.

The use of active acoustic solutions, i.e. acoustic deterrents and active sonar, in areas of interest (shipping, military exercises, gas exploration, etc.) to prevent unfortunate interactions is either range-limited and intrusive or ineffective on cetaceans, specially on those already highly tolerant to noise.

An alternative solution based on passive detection, classification and localization has been therefore considered. Here, we introduce a time and cost effective minimal solution applied to sperm whales - but technically applicable to other cetacean species - to an automatic real-time 3D whale localization.

3D PASSIVE LOCALIZATION

The 3D localization is based on the acoustic signal arrival time-delays and the assumption that sound propagation can be modeled by straight rays, resolving both the azimuth and elevation on a short aperture triangular array of passive sensors and the source distance from the time arrival on a distant fourth hydrophone (wide aperture array).

To predict the estimation error a 3D error map is created considering and discarding when appropriate the following error-sources :

•Sound speed error and the straight ray assumption

The speed of sound is highly depth-dependent and therefore the estimated average used will give a quantifiable error. We use an average such that this error is minimal at low depths, accepting that it will give some error when the whale is at greater depth. A frequency dependent curved ray solution of click propagation showed a few microseconds differences in arrival times compared with straight rays when whales were 2km deep within the range of interest (~ 5km).

•Cross-correlation peak time

The top array has a relatively short aperture (a 3m side equilateral triangle), which will play a large role in the positioning error. We need either a high sampling frequency or a fast interpolating filter and an accurate matching algorithm to precisely calculate the TDOA of a click at different hydrophones. Accordingly, we use a wide bandwidth (100Hz-24kHz) to take advantage of the click inherent broadband transient characteristic and interpolate 10 times to recreate the analog signal shape and avoid round-off errors due to Nyquist sampling.

With this configuration, the 3D localization algorithm calculates the whale's position in the 3000m water column and at a 5km diameter range with a 200m maximum error distance.

SILENT WHALE DETECTION

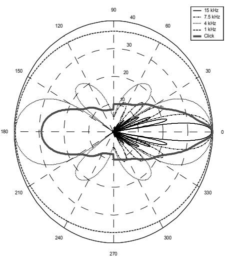
The system further integrates the tracking of acoustically passive whales by a sperm whale click-based ambient noise imaging sonar. As an alternative to conventional sonars, an innovative solution called Ambient Noise Imaging (ANI) fills the gap between active and passive solutions by using sound underwater in comparable ways as terrestrial life forms use daylight to visually sense their environment.

Instead of trying to reject the surrounding ocean background noise, ANI indirectly uses it as the illuminating source and searches the environment for a contrast created by an object underwater. The solution introduced here is conceptually based on both ANI and multi-static active solutions, where the active sources are produced by surrounding foraging sperm whales at greater depths (from 200 meters downwards), which vocalize on their way down and at foraging depths, and in reported cases, likely on their way up until a few minutes before surfacing.

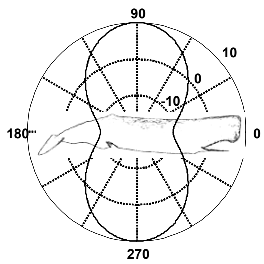
A simulation tool for 3D acoustic propagation was designed to simulate a bi-static solution formed of an arbitrary number of active acoustic sources, an illuminated object, and a receiver all positioned in 3D space with arbitrary bathymetry. Detection and bearing estimates could be performed for silent whales at ranges of 1500m from a 4m diameter array of 32 hydrophones, in a simulated scenario where on-axis click source and ambient noise levels were respectively 200dBrms re 1µPa @1m (full bandwidth) and 60 dBrms re 1µPa in the 1-10kHz band.

CONCLUSION

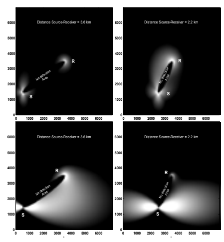
While an ambitious synthesis of many advanced acoustic technologies, the benefit is an efficient, non-intrusive system which can continuously 3D track cetaceans in areas of interest (shipping, gas exploration, military exercises, etc.), therefore mitigating the impact of artificial sound sources on marine mammal populations.



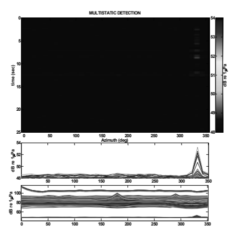
Composite beampattern of a click, created by applying its estimated power spectral density to a 0.8 m circular transducer that creates forward beams only from 5kHz upwards, and bidirectional beams downwards. The resulting click DI is 21.3 dB



Sperm whale target strength values in dB, function of aspect angle to the source in the 1-16kHz bandwidth for a 10 to 15m adult. The model is assumed invariant by rotation around the 0° axis



Signal Excess (SE) in gray dB scale, from 0 to 20dB (black to white) for a 7000m square area. S : active whale R : Receiver separated by 3,6 and 2,2km from left to right. Active whale is progressing left to right, while the object whale is progressing horizontally on top figures and vertically on bottom figures. Grayish and white areas represent the object whale locations that produce a positive detection threshold, while the "No detection area" accounts for both direct and object reflected signals arriving overlapped at the receiver.



Resulting image and received level plots, function of time and angle of arrival. The Ø4m-32-sensor-antenna forms 32 beams in azimuth, the levels of which are represented. The image colorbar is adjusted so that only levels between ambient noise level + 6 dB are displayed. This adjusted contrast allows clear highlight of the silent whale response to the others clicks at 330º. A projection of the cumulated result over the 25 second period is plotted below the image. Bottom figure is the same plot without adjusting the contrast. Beams are affected by the direct and reverberated paths taken from the vocal whales clicks directly to the buoy (all over 70dB).